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STUDY ON THE EQUIVALENT MODEL TEST AND ANALYSIS METHOD OF BRASH ICE AT KRISO ICE TANK

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ABSTRACT

Hull form design to satisfy minimum power requirement for Finnish-Swedish ice class rules is challenging work, it has to consider open water resistance (OW), self-propulsion (SP) performance, propeller open water (POW) performance, engine characteristics and ice performance in brash ice channel. KRISO has facilities of towing tank, cavitation tunnel (CT) and square type ice model basin. They have prepared entire process of verification of ship performance in brash ice. The computer added analysis program was developed to analysis of available net thrust for the designed vessel. Three PSV (Platform Supply Vessel) were designed for this study and carried out entire model test (OW, SP, POW and ice) as well.

Information of designed PSV vessel, results of CFD (Compute fluid dynamics) analysis, resistance in open water, self-propulsion performance, results of propeller open water performance and results of brash ice model test will be described in this paper. Brash ice model test scheme in KRISO, calculation method of channel resistance, minimum power requirement calculated by in-house software, results of available net thrust will be show. Entire process to do the brash ice model test and analysis for the designed vessel is summarized and the satisfaction of FMA (Finnish-Swedish Maritime Association) rule can be judged after analysis.

INTRODUCTION

All of vessels want to go Baltic Sea in winter season needs the permission of ice class grade from the Authorities. The Finnish Transport Safety Agency (Trafi) and the Swedish Transport Agency (STA) have developed and published the latest version of Finnish-Swedish Ice Class Rules in 2010. The rules define minimum engine outputs according to ice class glade IA, IB and IC respectively based on hull form, propeller type etc. Minimum engine output is calculated using the resistance (R_{CH}) of the vessel in a brash ice channel as like formula (3). R_{CH} can be determined by model testing in brash ice channel and also calculated according to the FSICR (Finnish Swedish Ice Class Rule) rules. To know R_{CH} by model test and for the commercial business, European ice facilities have set up their procedure for brash ice test with long history and plenty of experience but KRISO is about to carrying out commercial works for the Baltic ice class vessels. KRISO has square type ice model basin and started operating from 2009, their efforts to increase the uniformity of ice thickness and strength have researched in last five years. KRISO tested in various ice conditions such as pack ice, rubble ice and brash ice.

This paper is describing the research works to verify all of procedure of vessel performance in brash ice condition. The resistance tests, self-propulsion tests and propeller open water tests were performed in highly qualified KRISO's towing tank and cavitation tunnel respectively. Engine characteristics were analysed to know available net thrust. To apply procedure of KRISO brash ice test and analysis, three PSVs were designed. Best hull form was selected based on CFD analysis and all of model tests were carried out to know exact performance of designed vessel. All of test results in ice and ice free water will be shown and analysis results for the judgement of ice class glade will be decided as well.

VESSEL DESIGN

Designed PSV will be operating in ice and ice free water. Original or reference hull is selected on the data base of KRISO ('C' in Figure 2). First vessel ('B' in Figure 1 and Figure 2) was designed only for ice free water to increase open water performance, the purpose of second design ('A' in Figure 1 and Figure 2) is to increase performance in both conditions of ice and ice free water. Third or final design ('designed vessel' in Figure 1 and Figure 2) was modified for slightly increasing of open water performance. Principal dimension of final design is summarized in Table 1 and body plan is shown Figure 1. L/B ratio of designed vessel is 4.375, it's slightly higher than other vessels because performance in open water are needed to enhance and considered ice performance, so ship length is increased eventually. The design target is to have best performance in both waters.

Table 1. Principal Dimension of PSV

Items	Values	Abbreviations
Lpp ×B×draft (m)	87.5×20×6.5	Lpp : Length between Perpendicular B : Breadth of ship Cb : Block Coefficient
Volume (m^3)	7,928	
Surface area (m^2)	2.304	
Cb	0.697	
Speed (knots) in open sea	14.0	

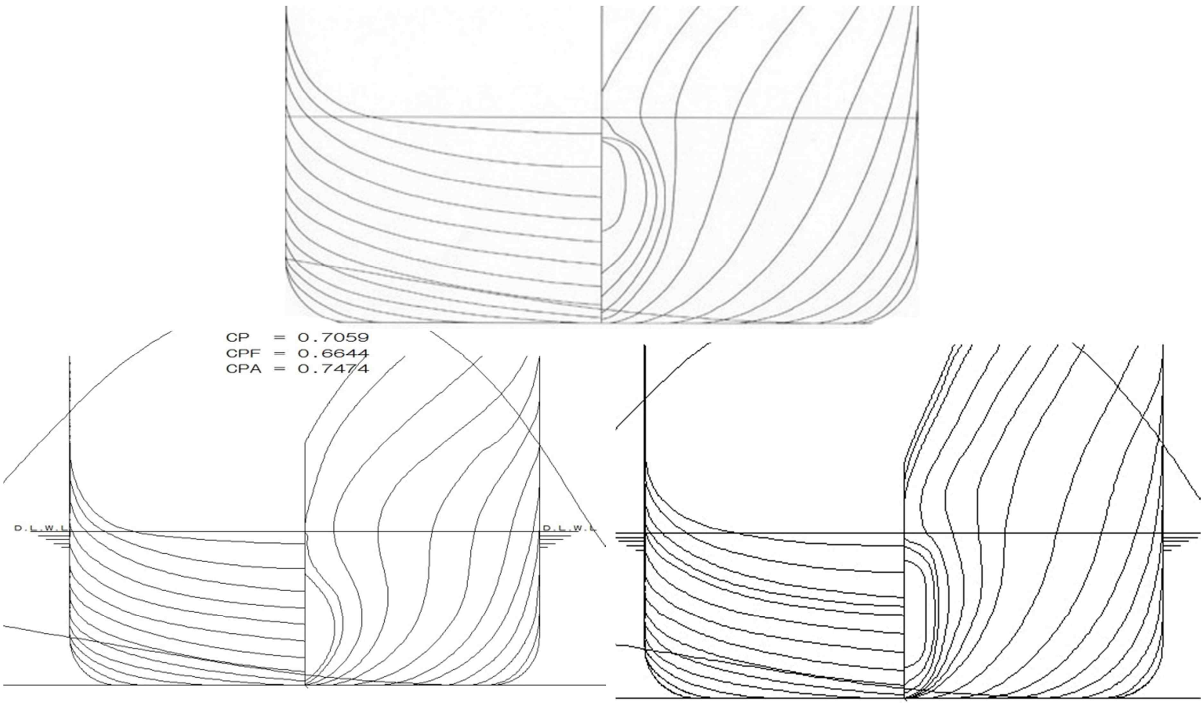

Figure 1. Body plans of vessels (Design Vessel:upper, A type:left below, B type:right below)

CFD analysis for the designed vessel and three alternatives was carried out by WAVIS version 1.3 which is in house potential code and commercially used in several shipyard and universities in Korea. CFD analysis results are shown in Figure 2. Wave height of designed vessel near bow and shoulder of ship has lowest value among alternative hull forms of A, B, C and designed vessel in Figure 2. It shows the resistance performance of designed hull form will be best among the alternatives.

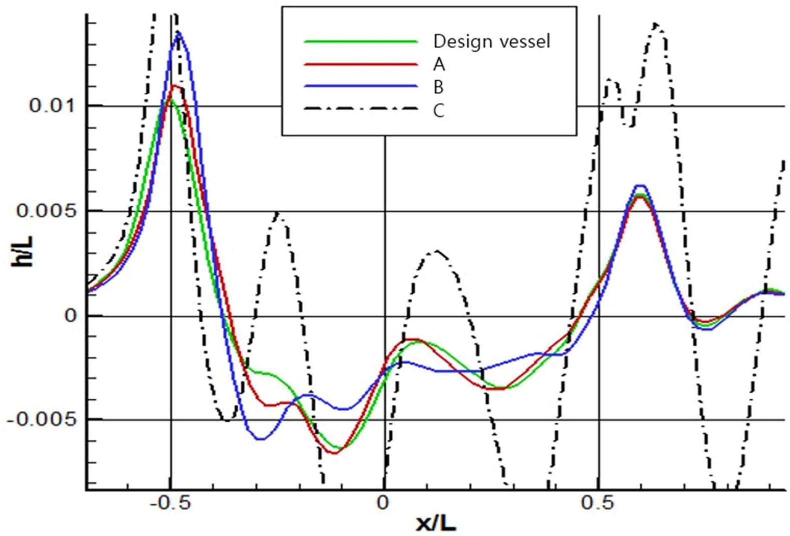

Figure 2. CFD results by WAVIS.

Stem and stern part of model ship was shown in Figure 3. Resistance test, self-propulsion test are performed in towing tank, resistance test in brash ice channel was carried out in the ice tank. Scale ratio of model test is 1:14.

Figure 3. Model ship of PSV.

Propulsion system of the PSV vessel is set twin ducted azimuth thruster in shown Figure 3. Main dimension of thruster is shown in Table 2. Diameter of propeller is 2.68m, number of blade is 4 and expanded area ratio is 1.0102.

Table 2. Main dimension of Propulsion system

Items	Values	Abbreviations
D(m)	2.68	D : Propeller diameter P/D : Pitch ratio Ae/Ao : Expanded are ratio Z : Number of blade
P/D (non-dimension)	1.175	
Ae/Ao(non-dimension)	1.0102	
Z	4	
No. of thruster	2	
Maximum power (MW)	2.5	

Figure 4 shows photo of ducted azimuth thruster in model scale. It was used in POW (Propeller Open Water), self-propulsion tests and brash ice channel test.

Figure 4. Model of ducted Azimuth thruster.

MODEL TEST RESULTS IN ICE FREE WATER.

Figure 5 shows wave profile in resistance test at ballast draft and 15 knots. The wave near bow and shoulder is very small and very similar to CFD analysis, so it is expected that the performance in ice free water will be good.

Figure 5. Photo of resistance test at 15 knots (ballast draft).

Analysis results (followed by ITTC 1957 method) of resistance test in ice free water at design draft were summarized in Figure 6. It shows delivery horse power (unit kW, left side) and propeller RPM (revolution per minute, right side) versus speed (Knots) between 11 knots and 15 knots without low speed range.

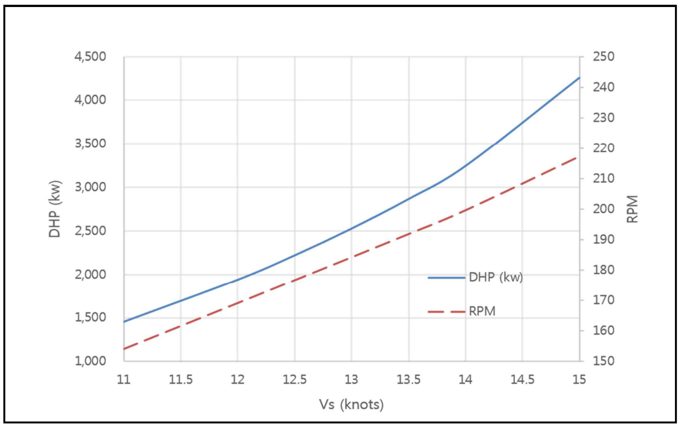

Figure 6. Results of resistance test in open water.

Ducted azimuth thruster was composed of duct, propeller and mounting body as shown in Figure 4. Propeller open water (POW) tests for duct and propeller itself were performed independently. The thrust coefficient and torque coefficient of duct, propeller and body were added to know total thrust coefficient of ducted azimuth thruster. Test results of POW were plotted on Figure 7.

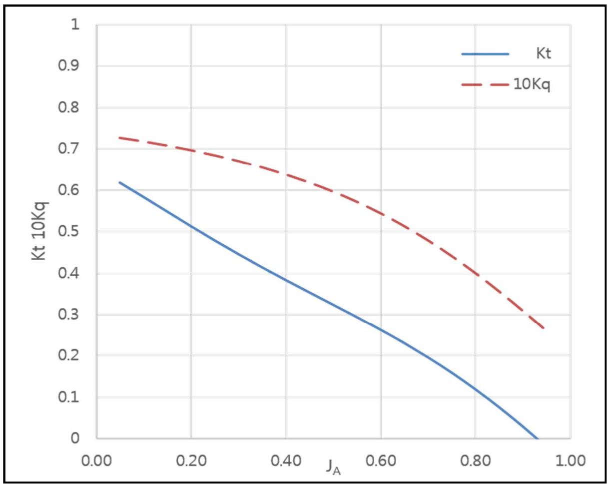

Figure 7. Results of propeller open water test.

To know self-propulsion coefficient (as like thrust deduction factor and wake), self-propulsion test were carried out in the high speed range between 11 knots and 15 knots. The results were summarized on Table 3. The wake and thrust deduction factor at 5 knots to calculate available net thrust were used mean value of Table 3.

Table 3. Results of self-propulsion test

Vs (knots)	Thrust deduction factor	Wake
11.0	0.175	0.179
12.0	0.178	0.181
13.0	0.180	0.184
14.0	0.183	0.187
15.0	0.185	0.192

MODEL TEST IN ICE TANK

Model ice of KRISO is quite different from European granular model ice. It's columnar ice of EG/AD (Ethylene Glycol Aliphatic Detergent) not a FG (Fine grain) ice. The manufacturing of brash ice channel is very hard work. Equivalent brash ice test scheme was recommended for the EG/AD, equivalent means that the volume of brash ice channel makes same as rule requirements. The size of broken ice piece has to less than 5 cm in model scale according to Guidance to make a similarity of brash ice in real scale. Profile of brash ice channel is defined by Guidelines for the application of the Finnish-Swedish ice class rules (2011) as shown Figure 8 and the relations between the cross-sectional areas are defined formula (1)

$$A_{CH} = A_1 + A_2 = A_2 + A_3 \quad (1)$$

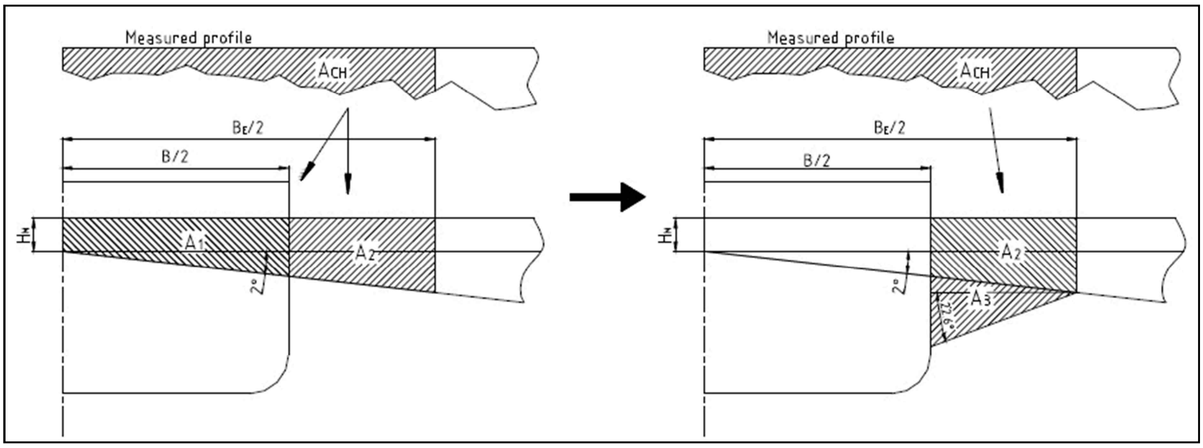

Figure 8. The geometry of a "real" brash ice channel profile before and after ship's passage. (B_E is Breadth of ice channel with 2 x B)

An average channel thickness (H_{av}) defined by formula (2).

$$H_{av} = H_M + 14.0\ 10^{-3}\ B \tag{2}$$

B is breadth of the ship and H_M is ice thickness for mid part of channel in formula (2) and Figure 8. H_M used 1m for IA ice grade, 0.8m for IB and 0.6 m for IC.

Guidelines for the application of the Finnish-Swedish ice class rules (2011) defines the width of the brash ice channel in model scale as 2B(two times of ship breadth) and measuring point of thickness profile of the ice channel defines as 1.6B(1.6 times of ship breadth) from the centre of channel. 1.7B is used for the brash ice channel width in this study because channel resistance of brash ice is expected not to high and some problem in preparation of brash ice channel.

Two or three ice thicknesses on the same draft are used for the model test normally because of the interpolation in the final results but only 0.5m ice thickness was used in this study and only one set of model test results for 0.5m ice thickness were used to analysis because of tight schedule of ice tank and budget. The reliability of analysis results has not high accuracy but entire process of this study is useful to set up the brash ice channel test and analysis.

To make a brash ice channel of 1.7B width, required volume of ice was calculated based on section profile of channel as shown Figure 8. First step is making brash ice with designed channel thickness as shown Figure 9. The ice piece size was broken smaller than 5cm model scale.

Figure 9. First step to make brash ice channel.

To make exact volume of brash ice channel, additional volume of ice was added in the channel as shown Figure 10 after the 100% pack ice test. Additional ice for the brash ice channel was delivered from the front side of ice tank in the same ice sheet.

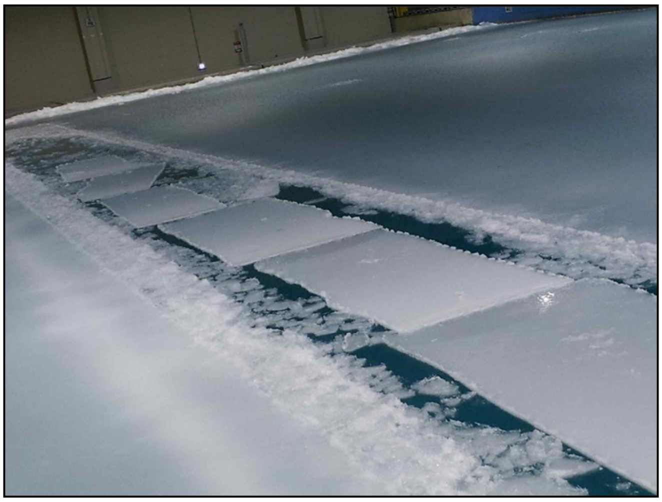

Figure 10. Filling up required volume of ice.

Figure 11 shows final preparation for brash ice channel of 1.7B width. Resistance test of brash ice channel at 5 knots was carried out and Figure 12 shows photo during the test. To check the uniformity of channel thickness, channel thickness was measured at 1.6 B position according to the Guidance. Figure 13 shows example of measuring channel thickness and the measured value is around 25cm in model scale. This value is very similar to calculation result with geometry of Figure 8.

Figure 11. Preparation of 1.7B brash ice channel.

Figure 12. Resistance test at brash ice channel.

Figure 13. Measuring of section profile which is parallel to course of ship.

ANALYSIS OF ICE GRADE

Although test are performed only one ice thickness and ice thickness is not exactly same as ice thickness (0.6m) of defined on the rule for IC, analysis to know ice grade of PSV was performed because one of purpose in this study is to check process of brash ice model test and analysis.

Minimum engine output was calculated based on Finnish-Swedish ice class rules (2002, BULLETIN No. 13) as like formula (3) and (4).

$$P = K_e \frac{(R_{CH}/1000)^{3/2}}{D_P} [kW] \tag{3}$$

Where Ke value is defined by the propeller number and types on the Finnish-Swedish ice class rules (2002, BULLETIN No. 13)

$$R_{CH} = C_1 + C_2 + C_3 C_\mu (H_F + H_M)^2 (B + C_\psi H_F) + C_4 L_{PAR} H_F^2 + C_5 \left(\frac{LT}{B^2}\right)^3 \frac{A_{wf}}{L} \quad (4)$$

Where coefficient C_1 to C_5 in (3) and other required coefficients which is component of C_1 to C_5 formula were followed by the definition in the Finnish-Swedish ice class rules (2002, BULLETIN No. 13).

The used values which are regarding hull form geometry for rule calculation are summarized in Table 4. In-house software of KRISO is possible to read data of Table 4 automatically because the software is available to display three dimensional CAD files.

Table 4. Used values for FMA Rule calculation

Items [unit]	Values
L, length of the ship between perpendiculars [m]	87.5
L_{BOW}, length of the bow [m]	30.63
L_{PAR}, length of the parallel middle body [m]	48.16
B, maximum breadth of the ship [m]	20
T, maximum ice class draught of the ship [m]	6.5
A_{wf}, area of the waterline of the bow [m2]	394.4
α , the angle of the waterline at B/4 [deg]	23.75
φ_1, the rake of the stem at the center line [deg]	90
φ_2, the rake of the bow at B/4 [deg]	51.15
D_p, diameter of the propeller [m]	2.68

Based on values from Table 4, channel resistance was calculated at different ice grade of IA super, IA, IB and IC. The coefficient in formula (4) are used according to the Guidance and ice thickness, propulsion type and number of propeller blade et al. are used based on designed PSV. The results of required minimum engine power were summarized in Table 5. The power of designed vessel has 5 MW, so designed PSV can be satisfied IA based on rule calculation. The ice resistance and available net thrust have to be checked to verify the satisfaction of ice class IA.

Table 5. Calculation results of Minimum engine output

Ice grade	Required minimum Power	
	BHP	kW
IA Super	8,804	6,474
IA	5,843	4,296
IB	3,970	2,919
IC	2,458	1,808

Figure 14 shows the flow chart to calculate available net thrust. This system was built by c# program language. Open water resistance (Figure 6), propeller open water characteristic (Figure 7) and self-propulsion coefficient (Table 3) were used to get available net thrust.

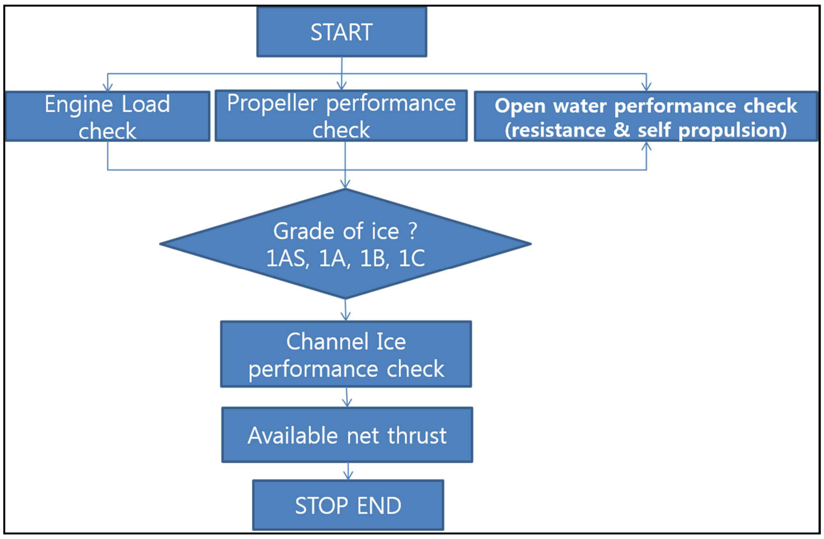

Figure 14. Flow chart of program to calculate available net thrust.

The relations between ship speed and available net thrust is displayed in Figure 15. Available net thrust is decreased if the ship speed is increasing normally because the resistance of ice free water is increasing if ship speed is going up. It means that there is small remain thrust for the ice if the ship speed is going up. The available net thrust at 5 knot is about 320 kN in Figure 15.

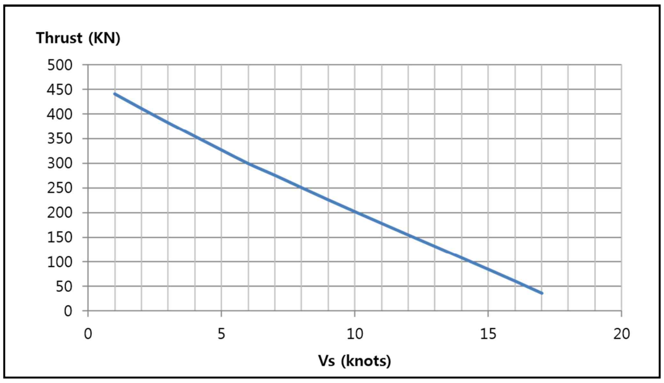

Figure 15. Calculation results of available net thrust.

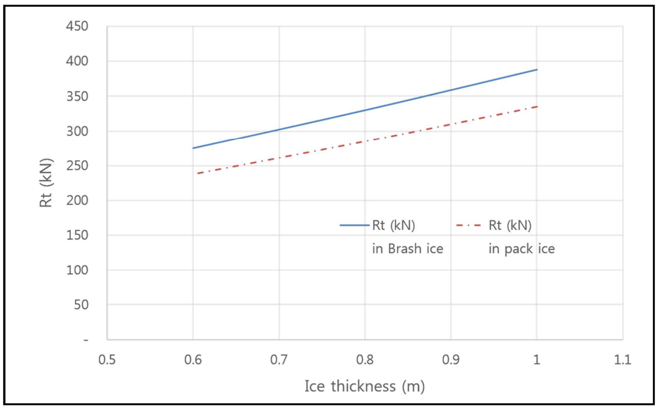

Figure 16 Results of ice resistance test.

The model test results of PSV is shown Figure 16 and the results shows ice thickness versus ice resistance of 100% pack ice and brash ice. The model test was carried out only 0.5m ice thickness, so the results at 0.6m, 0.8m and 1.0m are corrected by the HSVA method. Ice thickness and flexural strength were corrected. To scale up to real ship's resistance, λ^3 (λ is scale ratio) is used directly and plotted in Figure 16. The resistance in brash ice is greater than the values in pack ice as expected.

Figure 17 is summarized both resistance depend on ice thickness and available net thrust at 5 knots in brash ice. The crossing point between two lines is lower than 0.8m ice thickness and it means that PSV is not satisfying ice glade IB but satisfying IC because available net thrust is bigger than the resistance in ice at 0.6m

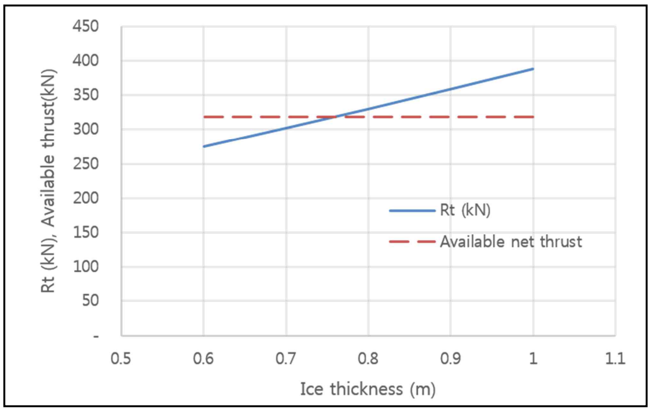

Figure 17 Performance of PSV in brash ice channel.

CONCLUSION AND FUTURE WORKS

The procedure of brash ice model test in KRISO and analysis scheme were described in the paper. Recommended brash ice channel is two times of ship breadth (2B) but PSV is tested at 1.7B channel width. Speed and ice thickness variation tests are not carried out in this study unfortunately. The correction method of HSVA is used for the other ice thickness and speed variation. The uniformity of measured brash ice channel is prepared successfully compare to the calculation results.

The procedure to analysis available net thrust and decision of ice grade were performed by the results of this study. Designed PSV is satisfying IC. The result of this study is not sufficient to receive the reliability from the client as a brash ice channel test but KRISO continue to develop for brash ice channel making and testing. Full set of model test results at 2B brash ice channel and analysis result will be presented near future.

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